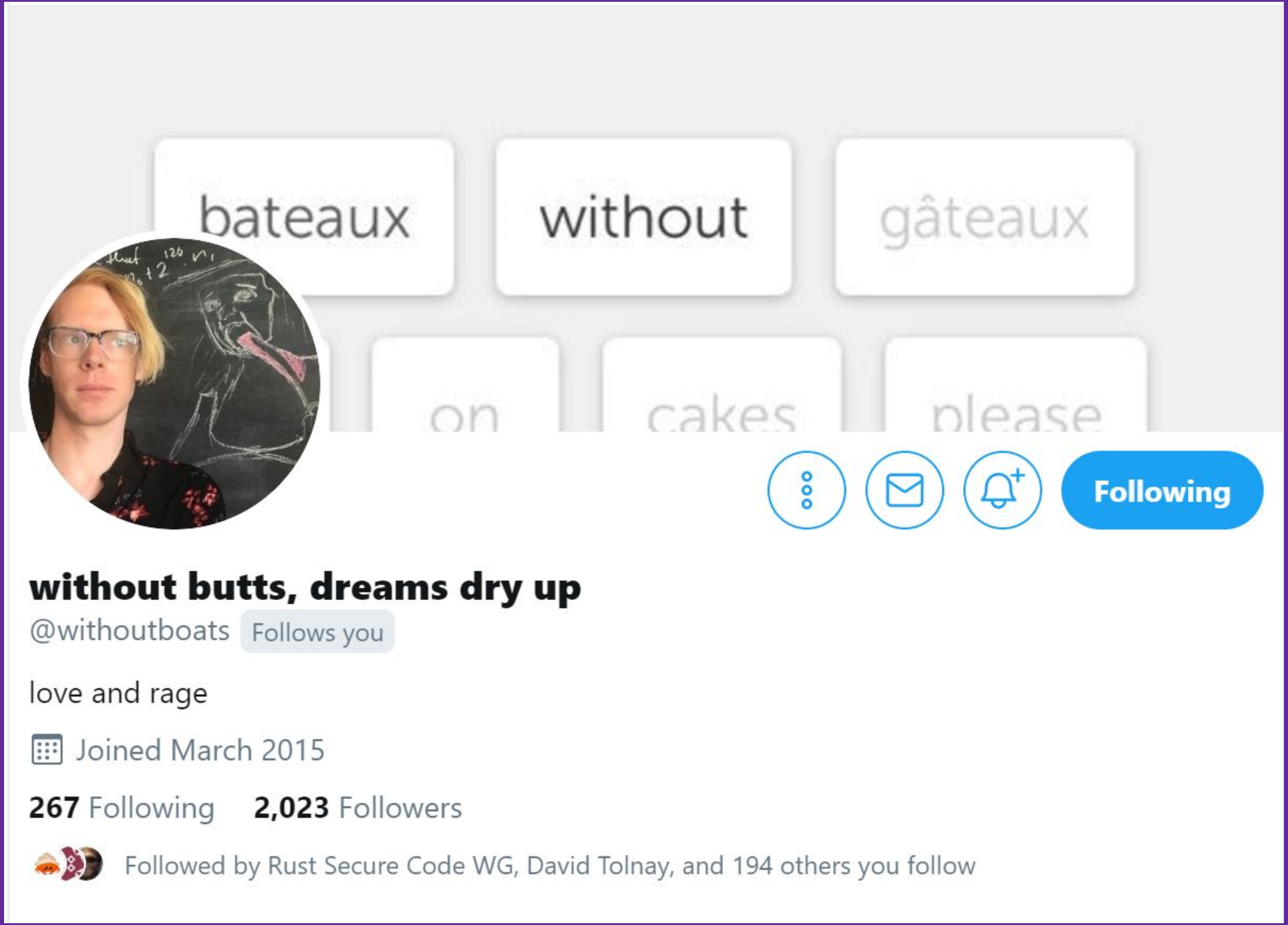
Rust's Journey to Async/Await

Steve Klabnik

Hi, I’m Steve!

- On the Rust team
- Work at Cloudflare
- Doing two workshops!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love and rage
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What is async?

Parallel: do multiple things at once

Concurrent: do multiple things, not at once

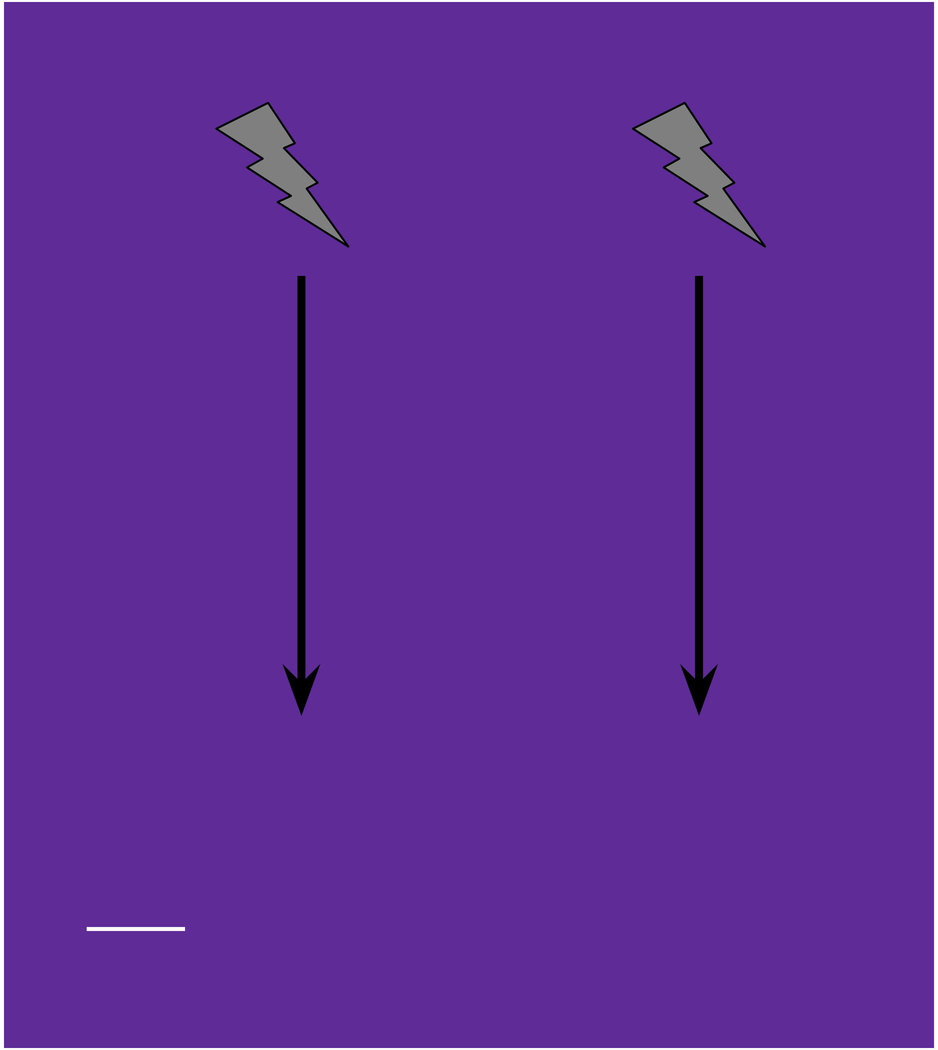
Asynchronous: actually unrelated! Sort of...

“Task”

A generic term for some computation running in a parallel or concurrent system

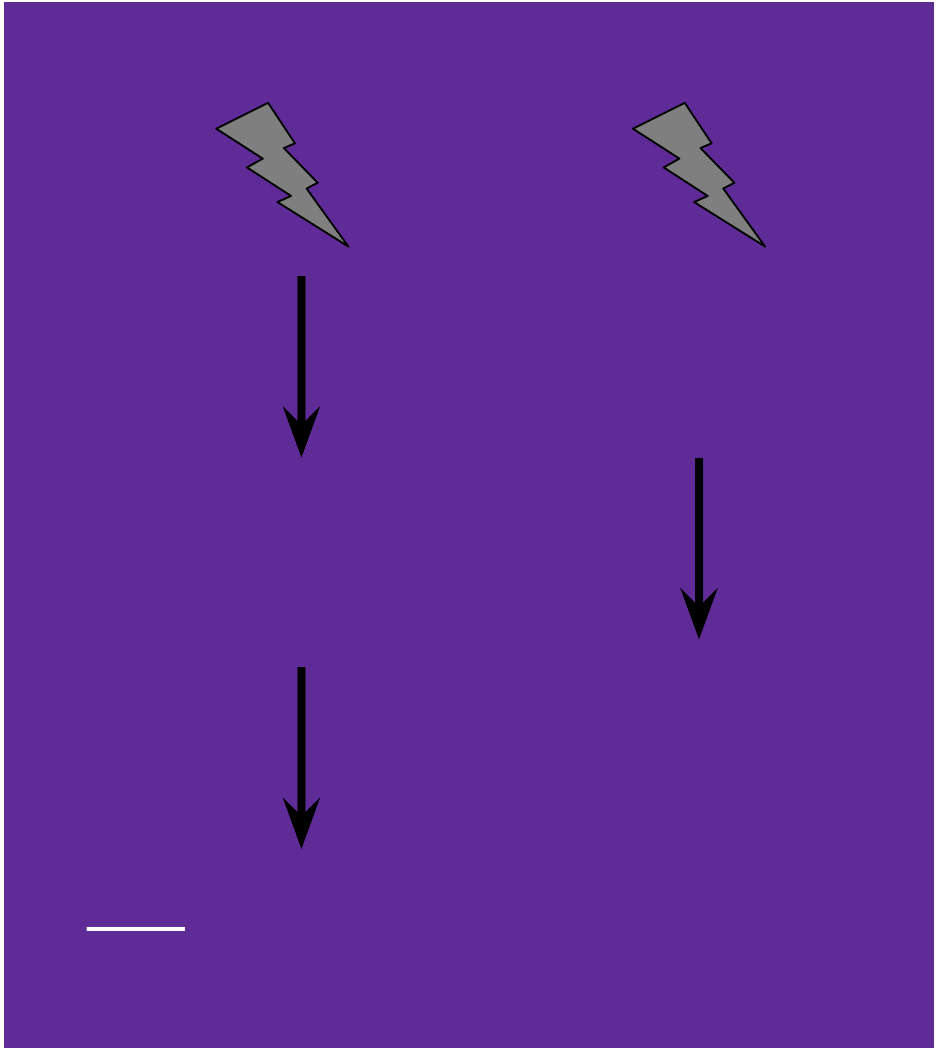
Parallel

Only possible with multiple cores or CPUs



Concurrent

Pretend that you have multiple cores or CPUs



Asynchronous

A word we use to describe language features that enable parallelism and/or concurrency

Even more terminology

Cooperative vs Preemptive Multitasking

Cooperative Multitasking

Each task decides when to yield to other tasks

Preemptive Multitasking

The system decides when to yield to other tasks

Native vs green threads

Native threads

Sometimes called “1:1 threading”

Tasks provided by the operating system

Green Threads

Sometimes called “N:M threading”

Tasks provided by your programming language

Native vs Green threads

Native thread advantages:

- Part of your system; OS handles scheduling
- Very straightforward, well-understood

Native thread disadvantages:

- Defaults can be sort of heavy
- Relatively limited number you can create

Green thread advantages:

- Not part of the overall system; runtime handles scheduling
- Lighter weight, can create many, many, many, many green threads

Green thread disadvantages:

- Stack growth can cause issues
- Overhead when calling into C

Why do we care?

The C10K problem

[Help save the best Linux news source on the web -- subscribe to Linux Weekly News!]

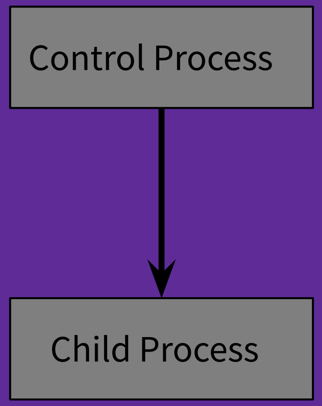
It's time for web servers to handle ten thousand clients simultaneously, don't you think? After all, the web is a big place now.

And computers are big, too. You can buy a 1000MHz machine with 2 gigabytes of RAM and an 1000Mbit/sec Ethernet card for $1200 or so. Let's see - at 20000 clients, that's 50KHz, 100Kbytes, and 50Kbits/sec per client. It shouldn't take any more horsepower than that to take four kilobytes from the disk and send them to the network once a second for each of twenty thousand clients. (That works out to $0.08 per client, by the way. Those $100/client licensing fees some operating systems charge are starting to look a little heavy!) So hardware is no longer the bottleneck.

In 1999 one of the busiest ftp sites, cdrom.com, actually handled 10000 clients simultaneously through a Gigabit Ethernet pipe. As of 2001, that same speed is now being offered by several ISPs, who expect it to become increasingly popular with large business customers.

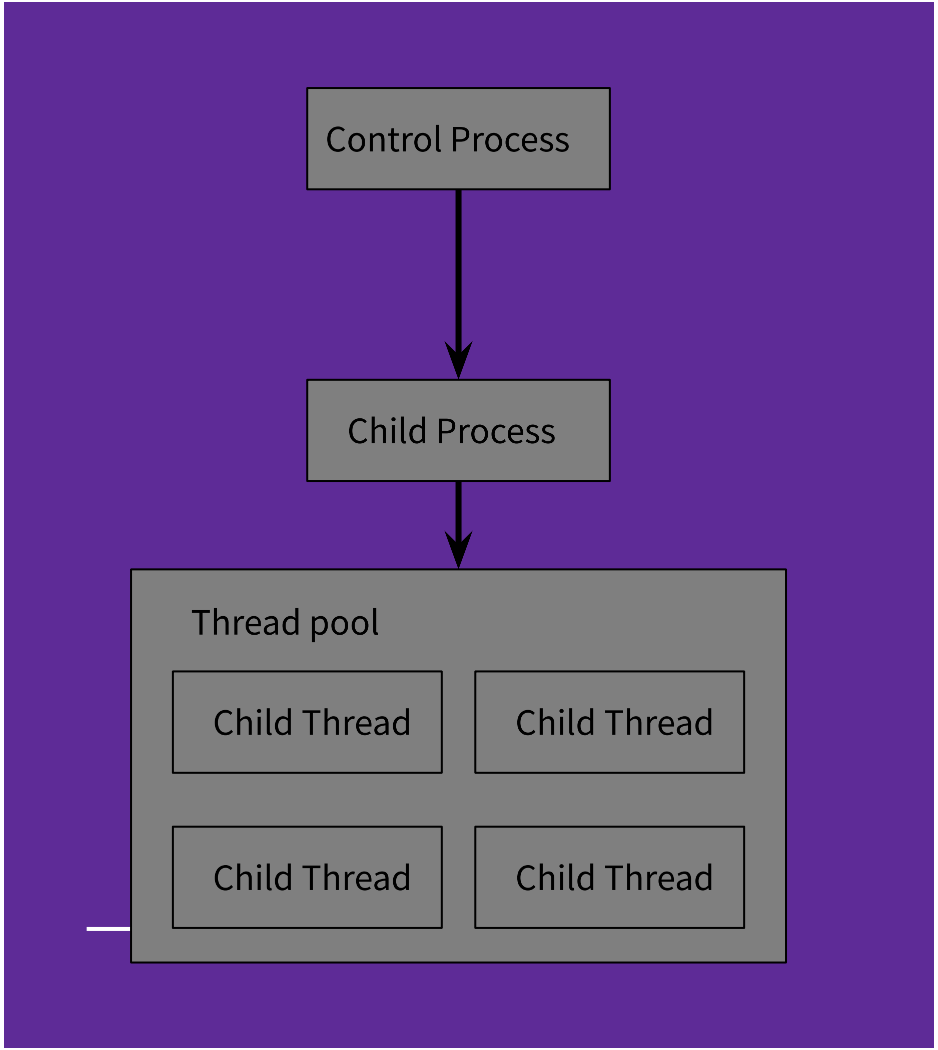
Apache

"Pre-fork"



Apache

"worker"



Let’s talk about Rust

Rust was built to enhance Firefox, which is an HTTP client, not server

https://doc.rust-lang.org/0.9/green/index.html

Search documentation...

Module green

The "green scheduling" library

This library provides M:N threading for rust programs. Internally this has the implementation of a green scheduler a
allocation strategy.

This can be optionally linked in to rust programs in order to provide M:N functionality inside of 1:1 programs.

MODULES

basic	This is a basic event loop implementation not meant for any "real purposes" other than testing the
context	

https://doc.rust-lang.org/0.9/std/io/net/index.html

Search documentation...

std::io

MODULES

- buffered
- comm_adapters
- extensions
- flate
- fs
- io_error
- mem
- net
- pipe

Module std::io::net

Synchronous, non-blocking network I/O. Synchronous, non-blocking network I/O.

REEXPORTS

```
pub use self::addrinfo::get_host_addresses;
```

MODULES

addrinfo	Synchronous DNS Resolution
ip	
tcp	
udp	
unix	Named pipes

“Synchronous, non-blocking network I/O”

Isn’t this a contradiction in terms?

	Synchronous	Asynchronous
Blocking	Old-school implementations	Doesn’t make sense
Non-blocking	Go, Ruby	Node.js

Tons of options

Synchronous, blocking

- Your code looks like it blocks, and it does block
- Very basic and straightforward

Asynchronous, non-blocking

- Your code looks like it doesn’t block, and it doesn’t block
- Harder to write

Synchronous, non-blocking

- Your code looks like it blocks, but it doesn’t!
- The secret: the runtime is non-blocking
- Your code still looks straightforward, but you get performance benefits
- A common path for languages built on synchronous, blocking I/O to gain performance while retaining compatibility

Not all was well in Rust-land

http://www.rust-lang.org/

3,772 captures

4 Sep 2011 - 24 Jun 2019

Docs (Nightly)

- Book
- Reference
- API docs
- All docs

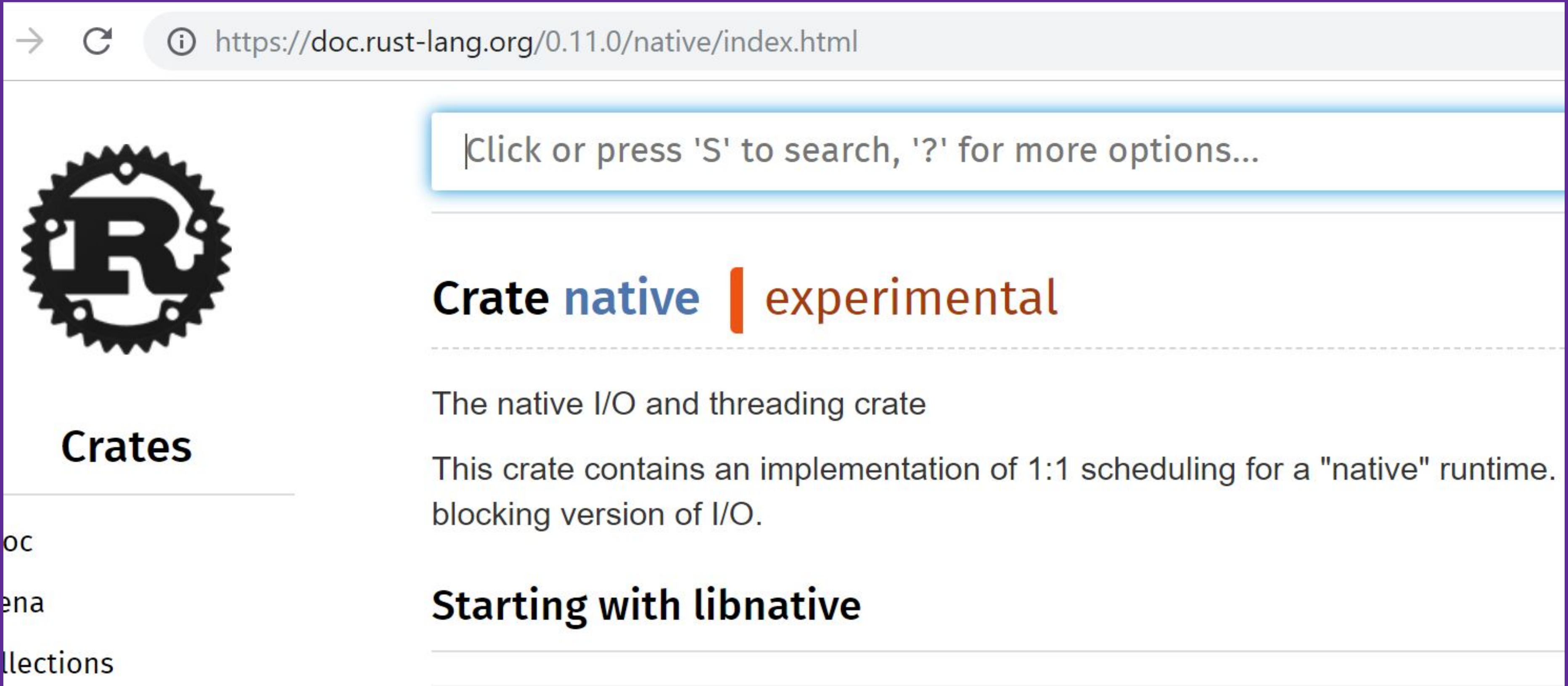
Docs (Alpha)

- Book
- Reference
- API docs
- All docs

Rust is a systems programming language that runs blazingly fast, prevents almost all crashes*, and eliminates data races.

Show me more!

A “systems programming language” that doesn’t let you use the system’s threads?


https://doc.rust-lang.org/0.11.0/native/index.html
Click or press 'S' to search, '?' for more options...
Crate native
experimental
The native I/O and threading crate
This crate contains an implementation of 1:1 scheduling for a "native" runtime.
blocking version of I/O.
Starting with libnative
Crates
oc
ena
llections

https://doc.rust-lang.org/0.11.0/green/index.html

Click or press 'S' to search, '?' for more options...

Crates

oc

ena

llections

Crate green experimental

The "green scheduling" library

This library provides M:N threading for rust programs. Inte
switching and a stack-allocation strategy. This can be opti
programs.

Architecture

In today's Rust, there is a single I/O API -- `std::io` -- that provides blocking operations only and works with both threading models. Rust is somewhat unusual in allowing programs to mix native and green threading, and furthermore allowing *some* degree of interoperation between the two. This feat is achieved through the runtime system -- `librustrt` -- which exposes:

- The `Runtime` trait, which abstracts over the scheduler (via methods like `deschedule` and `spawn_sibling`) as well as the entire I/O API (via `local_io`).

- The `rtio` module, which provides a number of traits that define the standard I/O abstraction.

- The `Task` struct, which includes a `Runtime` trait object as the dynamic entry point into the runtime.

In this setup, `libstd` works directly against the runtime interface. When invoking an I/O or scheduling operation, it first finds the current `Task`, and then extracts the `Runtime` trait object to actually perform the operation.

Not all was well in Rust-land

GitHub, Inc. [US] https://github.com/rust-lang/rfcs/blob/master/text/0230-remove-runtime.md

Summary

This RFC proposes to remove the *runtime system* that is currently part of the standard library, which currently allows the standard library to support both native and green threading. In particular:

- The `libgreen` crate and associated support will be moved out of tree, into a separate Cargo package.
- The `librustrt` (the runtime) crate will be removed entirely.
- The `std::io` implementation will be directly welded to native threads and system calls.
- The `std::io` module will remain completely cross-platform, though *separate* platform-specific modules may be added at a later time.

Rust 1.0 was approaching

Ship the minimal thing that we know is good

Rust 1.0 was released! ~~🎉~~

… but still, not all was well in Rust-land

People ~~💖~~ Rust

People want to build network services in Rust

Rust is supposed
to be a
high-performance
language

Rust’s I/O model feels retro, and not performant

The big problem with native threads for I/O

CPU bound vs
I/O bound

CPU Bound

My processor is working hard

The speed of completing a task is based on the CPU crunching some numbers

I/O Bound

Doing a lot of networking

The speed of completing a task is based on doing a lot of input and output

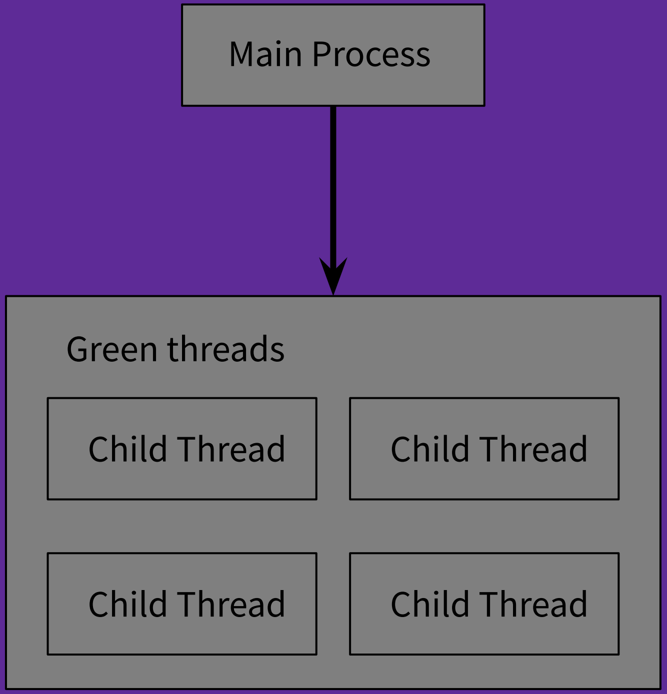
When you’re
doing a lot of I/O,
you’re doing a lot
of waiting

When you’re doing a lot of waiting, you’re tying up system resources

Go

Asynchronous I/O
with green threads

(Erlang does this too)



Native vs Green threads

PREVIOUSLY

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Native thread disadvantages:

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Green thread disadvantages:

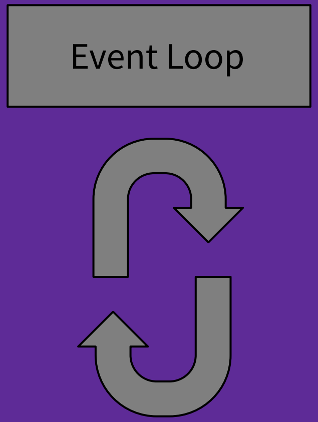
- Stack growth can cause issues
- Overhead when calling into C

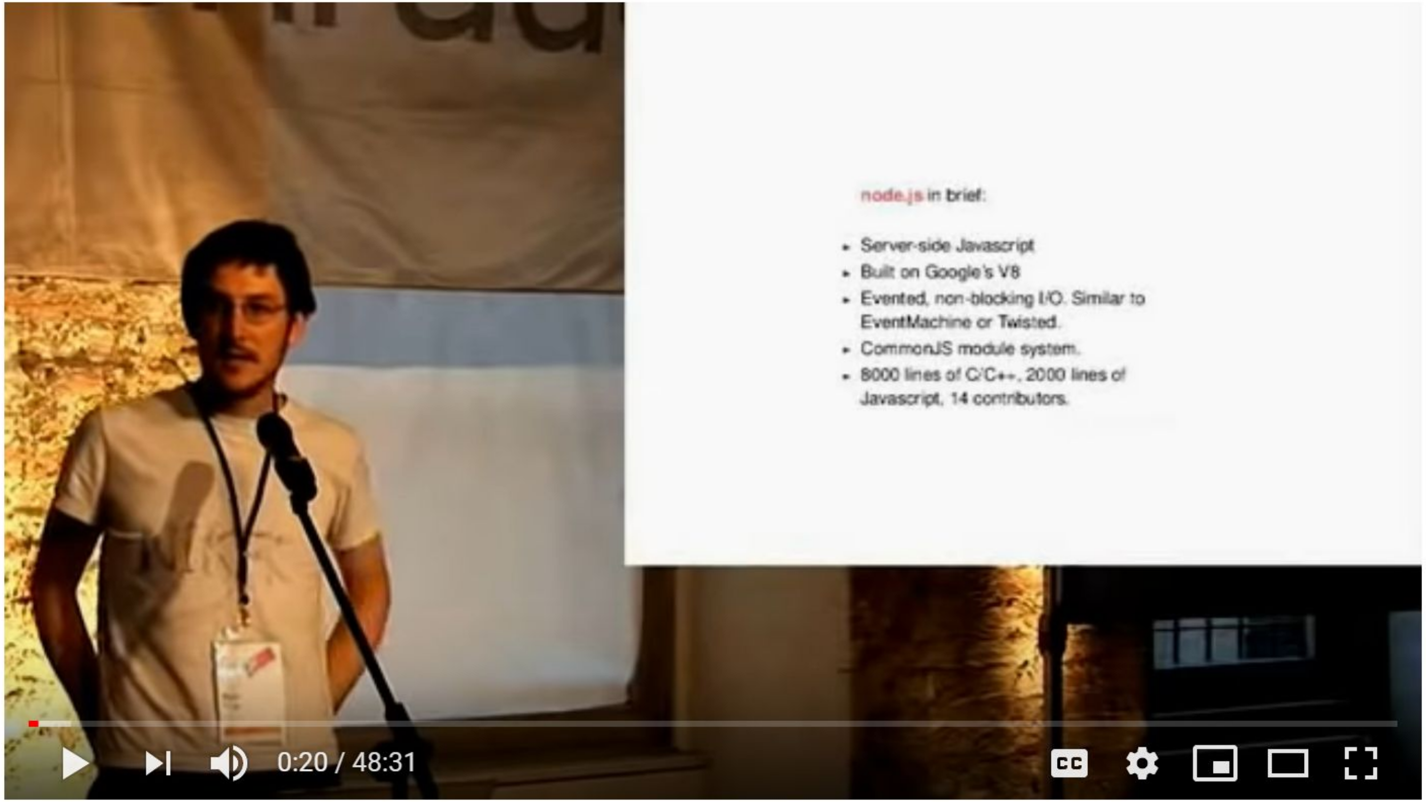
A “systems programming language” that has overhead when calling into C code?

Luckily, there is another way

Nginx

Asynchronous I/O





Ryan Dahl: Original Node.js presentation

166,252 views 2.5K 27 SHARE SAVE

Evented I/O requires non-blocking APIs

Blocking vs non-blocking

Using the File System module as an example, this is a **synchronous** file read:

```
const fs = require('fs');
const data = fs.readFileSync('/file.md'); // blocks here until file is read
```

And here is an equivalent **asynchronous** example:

```
const fs = require('fs');
fs.readFile('/file.md', (err, data) => {
  if (err) throw err;
});
```

“Callback hell”

callbackhell.com

Callback Hell

A guide to writing asynchronous JavaScript programs

What is "*callback hell*"?

Asynchronous JavaScript, or JavaScript that uses callbacks, is hard to get right intuitively. A lot of code ends up looking like this:

```
fs.readdir(source, function (err, files) {
  if (err) {
    console.log('Error finding files: ' + err)
  } else {
    files.forEach(function (filename, fileIndex) {
      console.log(filename)
      gm(source + filename).size(function (err, values) {
        if (err) {
          console.log('Error identifying file size: ' + err)
        } else {
          console.log(filename + ' : ' + values)
          aspect = (values.width / values.height)
          widths.forEach(function (width, widthIndex) {
            height = Math.round(width / aspect)
            console.log('resizing ' + filename + 'to ' + height + 'x' + height)
            this.resize(width, height).write(dest + 'w' + width + '_' + filename, function(err) {
              if (err) console.log('Error writing file: ' + err)
            })
          }.bind(this))
        }
      })
    })
  }
})
```

A **`Promise`** is a proxy for a value not necessarily known when the promise is created. It allows you to associate handlers with an asynchronous action's eventual success value or failure reason. This lets asynchronous methods return values like synchronous methods: instead of immediately returning the final value, the asynchronous method returns a *promise* to supply the value at some point in the future.

A `Promise` is in one of these states:

- *pending*: initial state, neither fulfilled nor rejected.
- *fulfilled*: meaning that the operation completed successfully.
- *rejected*: meaning that the operation failed.

Promises

```
let myFirstPromise = new Promise((resolve, reject) => {
   setTimeout(function(){
    resolve("Success!");
  }, 250);
});

myFirstPromise.then((successMessage) => {
   console.log("Yay! " + successMessage);
});
```

Promises

```
let myFirstPromise = new Promise((resolve, reject) => {
   setTimeout(function(){
    resolve("Success!");
  }, 250);
});

myFirstPromise.then((successMessage) => {
   console.log("Yay! " + successMessage);
}).then((...) => {
   //
}).then((...) => {
   //
});
```

Your Server as a Function

Marius Eriksen
Twitter Inc.
marius@twitter.com

Abstract

Building server software in a large-scale setting, where systems exhibit a high degree of concurrency and environmental variability, is a challenging task to even the most experienced programmer. Efficiency, safety, and robustness are paramount—goals which have traditionally conflicted with modularity, reusability, and flexibility.

We describe three abstractions which combine to present a powerful programming model for building safe, modular, and efficient server software: Composable *futures* are used to relate concurrent, asynchronous actions; *services* and *filters* are specialized functions

Services Systems boundaries are represented by asynchronous functions called *services*. They provide a symmetric and uniform API: the same abstraction represents both clients and servers.

Filters Application-agnostic concerns (e.g. timeouts, retries, authentication) are encapsulated by *filters* which compose to build services from multiple independent modules.

Server operations (e.g. acting on an incoming RPC or a timeout) are defined in a declarative fashion, relating the results of the (possibly many) subsequent sub-operations through the use of fu-

Zero-cost futures in Rust

11 Aug 2016

One of the key gaps in Rust's ecosystem has been a strong story for fast and productive *asynchronous I/O*. We have solid foundations, like the mio library, but they're very low level: you have to wire up state machines and juggle callbacks directly.

We've wanted something higher level, with better ergonomics, but also better *composability*, supporting an ecosystem of asynchronous abstractions that all work together. This story might sound familiar: it's the same goal that's led to the introduction of *futures* (aka promises) in many languages, with some supporting *async/await* sugar on top.

A major tenet of Rust is the ability to build zero-cost abstractions, and that leads to one additional goal for our async I/O story: ideally, an abstraction like futures should compile down to something equivalent to the state-machine-and-callback-juggling code we're writing today (with no additional runtime overhead).

Futures 0.1

```
pub trait Future {
  type Item;
  type Error;

  fn poll(&mut self) -> Poll<Self::Item, Self::Error>;
}

id_rpc(&my_server).and_then(|id| {
    get_row(id)
}).map(|row| {
    json::encode(row)
}).and_then(|encoded| {
    write_string(my_socket, encoded)
})
```

Promises and Futures are different!

- Promises are built into JavaScript
- The language has a runtime
- This means that Promises start executing upon creation
- This feels simpler, but has some drawbacks, namely, lots of allocations

- Futures are not built into Rust
- The language has no runtime
- This means that you must submit your futures to an executor to start execution
- Futures are inert until their `poll` method is called by the executor
- This is slightly more complex, but **extremely** efficient; a single, perfectly sized allocation per task!
- Compiles into the state machine you'd write by hand with evented I/O

Futures 0.1: Executors

```
use tokio;

fn main() {
    let addr = "127.0.0.1:6142".parse().unwrap();
    let listener = TcpListener::bind(&addr).unwrap();

    let server = listener.incoming().for_each(|socket| {
        Ok(())
    })
    .map_err(|err| {
        println!("accept error = {:?}", err);
    });

    println!("server running on localhost:6142");

   tokio::run(server);
}
```

We used Futures 0.1 to build stuff!

The design had some problems

Futures 0.2

```
trait Future {
    type Item;
    type Error;

    fn poll(&mut self, cx: task::Context) ->
Poll<Self::Item, Self::Error>;
}
```

No implicit context, no more need for thread local storage.

aturon rust 36 points · 1 year ago

> Would you suggest that the ecosystem goes through two breaking changes (now and for 0.3) or should libraries like Tokio maintain support for both 0.1 and 0.2 and then have a single breaking change when 0.3 is released.

The latter. I consider 0.2 a "snapshot" that's good for experimentation but shouldn't be used heavily, since stable 0.3 should be coming in a couple of months or less.

Give Award Share Report Save

sdroege_ 28 points · 1 year ago

This seems to be counterproductive. If you want people to experiment with the changes they need their dependencies using futures 0.2. Otherwise any experimentation would only be possible for completely standalone things and not even on top of tokio or hyper, and that would limit the amount of feedback you get a lot. Especially with regards to usability.

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Async/await

```
// with callback
request('https://google.com/', (response) => {
  // handle response
})

// with promise
request('https://google.com/').then((response) => {
  // handle response
});

// with async/await
async function handler() {
  let response = await request('https://google.com/')
  // handle response
}
```

Async/await lets you write code that feels synchronous, but is actually asynchronous

Async/await is more important in Rust than in other languages because Rust has no garbage collector

Rust example: synchronous

```
fn read(&mut self, buf: &mut [u8]) -> Result<usize, io::Error>
```

```
let mut buf = [0; 1024];
let mut cursor = 0;

while cursor < 1024 {
    cursor += socket.read(&mut buf[cursor..])?;
}
```

Rust example: async with Futures

```
fn read<T: AsMut<[u8]>>(self, buf: T) ->
    impl Future<Item = (Self, T, usize), Error = (Self, T, io::Error)>
```

… the code is too big to fit on the slide

The main problem: the borrow checker doesn’t understand asynchronous code.

The constraints on the code when it’s created and when it executes are different.

Rust example: async with async/await

```
async {
    let mut buf = [0; 1024];
    let mut cursor = 0;

    while cursor < 1024 {
        cursor += socket.read(&mut buf[cursor..]).await?;
    };

    buf
}
```

`async/await` can teach the borrow checker about these constraints.

Not all futures can error

```
trait Future {
    type Item;
    type Error;

    fn poll(&mut self, cx: task::Context) ->
Poll<Self::Item, Self::Error>;
}
```

std::future

```
pub trait Future {
    type Output;

    fn poll(self: Pin<&mut Self>, cx: &mut Context)
-> Poll<Self::Output>;
}
```

`Pin` is how `async/await` teaches the borrow checker.

If you need a future that errors, set `Output` to a `Result<T, E>`.

... but one more thing...

What syntax for async/await?

`async` is not an issue

JavaScript and C# do:

```
await value;
```

But what about `?` for error handling?

```
await value?;
```

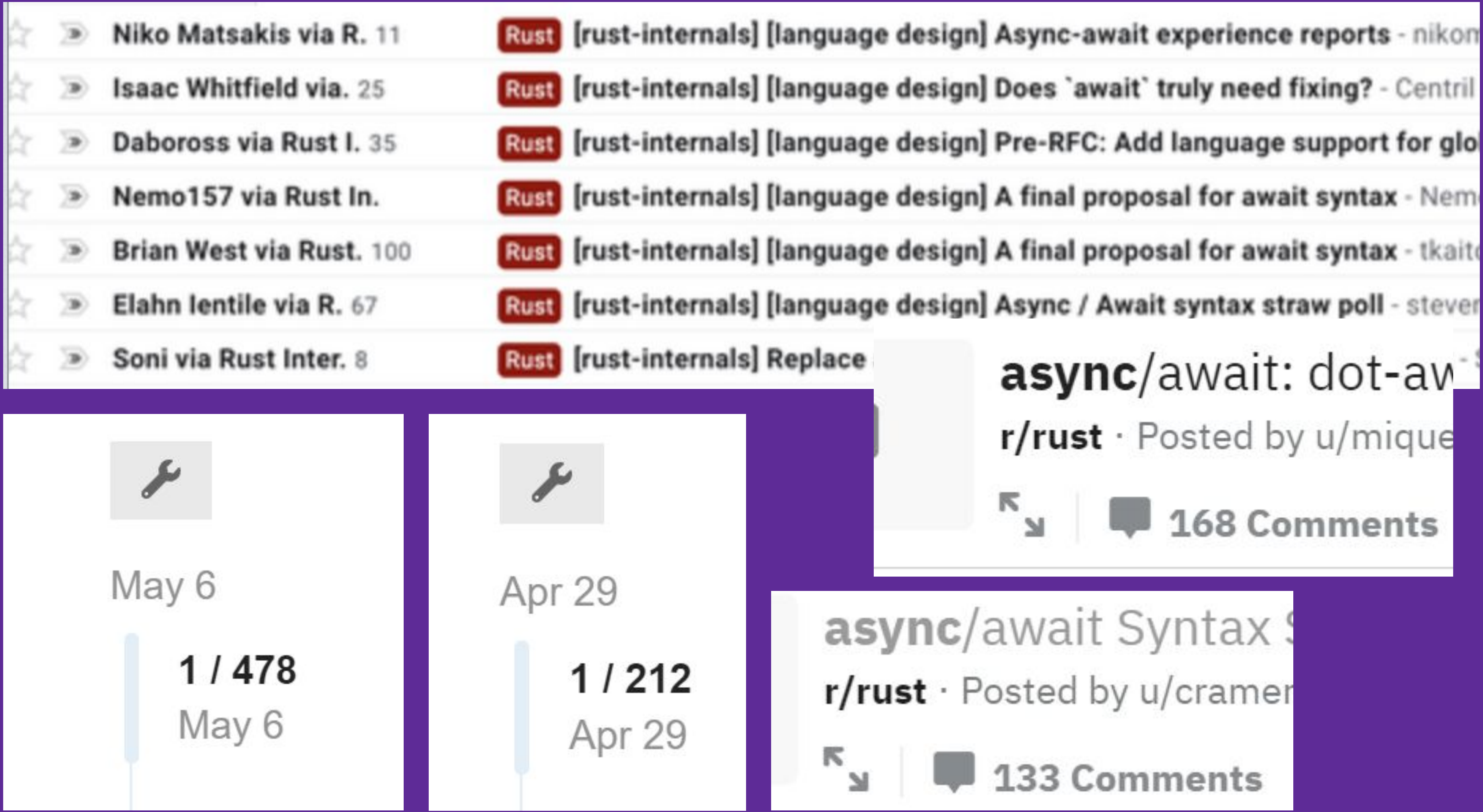
```
await (value?);
(await value)?;
```

What syntax for async/await?

What about chains of `await`?

```
(await (await value)?);
```

We argued and
argued and
argued and
argued and
argued and ar...


Niko Matsakis via R. 11
Rust
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Isaac Whitfield via. 25
Rust
[rust-internals] [language design] Does `await` truly need fixing? - Centril
Daboross via Rust I. 35
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[rust-internals] [language design] Pre-RFC: Add language support for glo
Nemo157 via Rust In.
Rust
[rust-internals] [language design] A final proposal for await syntax - Nem
Brian West via Rust. 100
Rust
[rust-internals] [language design] A final proposal for await syntax - tkaitc
Elahn Ientile via R. 67
Rust
[rust-internals] [language design] Async / Await syntax straw poll - steve
Soni via Rust Inter. 8
Rust
[rust-internals] Replace
async/await: dot-aw
r/rust · Posted by u/mique
168 Comments
May 6
1 / 478
May 6
Apr 29
1 / 212
Apr 29
async/await Syntax
r/rust · Posted by u/cramer
133 Comments

What syntax for async/await?

```
async {
    let mut buf = [0; 1024];
    let mut cursor = 0;

    while cursor < 1024 {
        cursor += socket.read(&mut buf[cursor..]).await?;
    };

    buf
}
```

```
// no errors
future.await
// with errors
future.await?
```

… there’s actually
even one last
issue that’s
popped up

… this talk is already long enough

Additional Ergonomic improvements

```
use runtime::net::UdpSocket;

#[runtime::main]
async fn main() -> std::io::Result<()> {
    let mut socket = UdpSocket::bind("127.0.0.1:8080")?;
    let mut buf = vec![0u8; 1024];

    println!("Listening on {}", socket.local_addr()?);

    loop {
        let (recv, peer) = socket.recv_from(&mut buf).await?;
        let sent = socket.send_to(&buf[..recv], &peer).await?;
        println!("Sent {} out of {} bytes to {}", sent, recv, peer);
    }
}
```

WebAssembly?

```rust
#[wasm_bindgen]
pub fn wasm_entry(path: String, data: Data) -> Promise {
    future_to_promise(async move {
        let path = PathBuf::from(path);

        let future = JsFuture::from(data.get(path.to_str().unwrap()));
        let contents = future
            .await
            .expect("couldn't fetch page data")
            .as_string()
            .expect("couldnt get a string");

        let response = Response {
            body,
            status_code: 200,
            content_type,
        };

        JsValue::from_serde(&response).map_err(|_| JsValue::from_str("cou
    })
}
```

WebAssembly?

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#[wasm_bindgen]
pub fn wasm_entry(path: String, data: Data) -> Promise {
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    })
}
```

Promise

Future

Promise

Finally landing in Rust 1.37

Or maybe 1.38

~~Finally landing in Rust 1.37~~

~~Or maybe 1.38~~

without butts, dreams dry up
@withoutboats

Storm warning: comment hurricane incoming on the rust repo. We are stabilizing async/await

[Stabilization] async/await MVP · Issue #62149 · rust-lang/rust
Stabilization target: 1.38.0 (beta cut 2019-08-15) Executive Summary This is a proposal to stabilize a minimum viable async/await feature, ...
github.com

7:47 AM · Jun 26, 2019 · Twitter for iPhone

29 Retweets **95** Likes

Finally landing in Rust 1.38!!!!1

JSON serialization | Single query | Multiple queries | **Fortunes** | Data updates | Plaintext

Fortunes

Best (bar chart) | Data table | Latency | Framework overhead

Best fortunes responses per second, Test environment (368 tests)

Rnk	Framework	Best performance (higher is better)	
1	actix-core	699,975	100.0%
2	actix-pg	630,441	90.1%
3	atreugo-prefork-quicktemplate	435,042	62.2%

Lesson: a world-class I/O system implementation takes years

Lesson: different languages have different constraints

Thank you!

@steveklabnik